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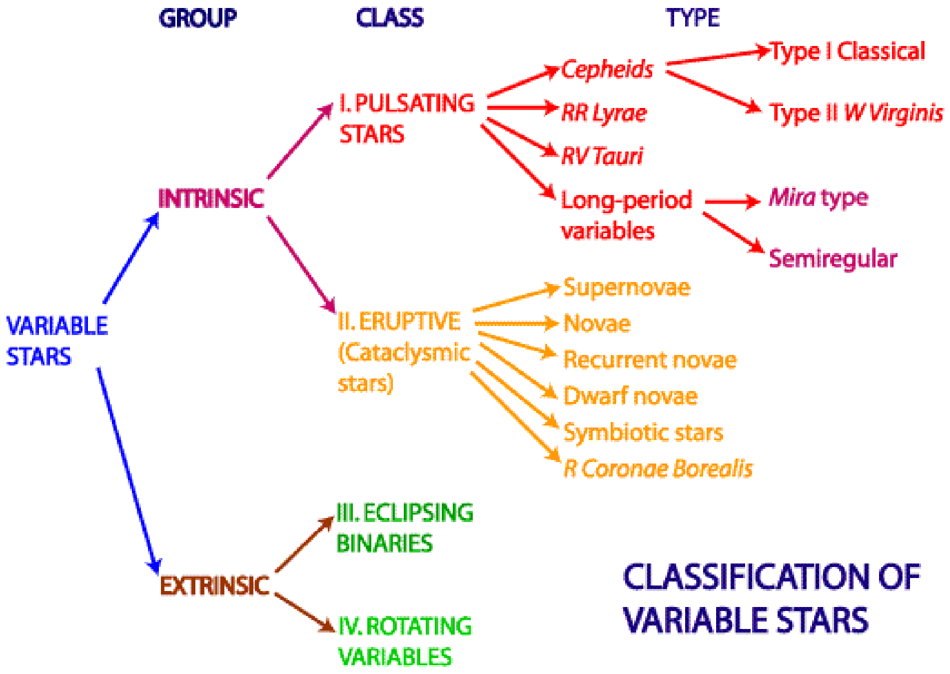
Variable Stars

When we look up at the night sky it is easy to imagine that the stars are unchanging. Apart from twinkling due to the effects of our atmosphere stars appear fixed and constant to the untrained eye. Careful observations, some even done with the naked eye, show that some stars do in fact appear to change in brightness over time. Some exhibit periodic behaviour, brightening quickly then diminishing in brightness slowly only to repeat themselves. With some these changes take place over several days whilst others occur in a matter of hours or many months. Other stars exhibit a once-off dramatic change in brightness by orders of magnitude before fading away to obscurity. All of these are examples of what are termed variable stars. A variable star is simply one whose brightness (or other physical property such as radius or spectral type) changes over time.

At a fundamental level all stars are variable as they evolve and change over time (from a main sequence to a red giant star as in the Sun's case for example). Furthermore we can infer that all stars are likely to vary their light output to some extent due to variations caused by phenomena such as sunspots. In the section however, we focus on stars with a measurable change in brightness. In order to try and understand variable stars, astronomers have sought to classify them according to observable properties. The diagram below the main types of variable stars.



Classification diagram for variable stars. Clicking on a term will take you to more information. Note the details on types of pulsating variables will take you to the next page.

The first criteria for classification is whether a star in an intrinsic or an extrinsic variable. **Intrinsic variables** are those in which the change in brightness is due to some change within the star itself such as in pulsating stars like the Cepheids. **Extrinsic variables** are those in which the light output changes due to some process external to the star itself. The most common example of these are the eclipsing binaries. Brief details on the major classes are provided below whilst the pulsating variables are discussed in more detail on the next page.

Intrinsic Variables

These are stars which vary their light output, hence their brightness, by some change within the star itself. They are an extremely important and useful group of stars to astronomers as they provide a wealth of information about the internal structure of stars and models of stellar evolution. Perhaps their greatest value is the role of some types such as Cepheids and supernovae in distance determination. Intrinsic variables are further classified as to whether they exhibit periodic pulsations are more explosive or eruptive events as in cataclysmic variables.

Pulsating Variables

Pulsating variables periodically expand and contract their surface layers. In the process they change their size, effective temperature and spectral properties. As they are a vital tool in galactic and extragalactic distance determination and have many types they are discussed in more detail on separate pages.

Eruptive or Cataclysmic Variables

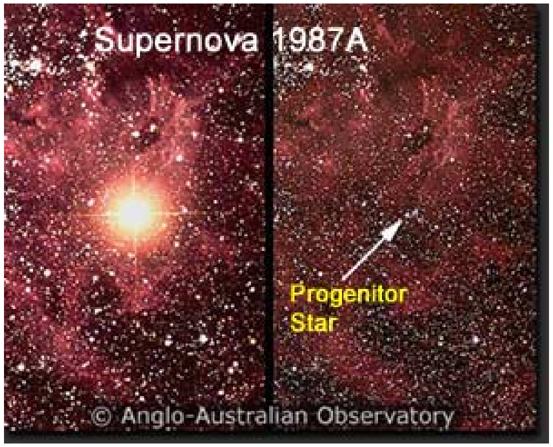
Eruptive variables can exhibit significant and rapid changes in their luminosity due to violent outbursts caused by processes within the star. There is a wide variety of eruptive or cataclysmic variables. Some event, as implied by the term cataclysmic result in the destruction of the star whilst others can reoccur one or more times. More details on the different types are provided below. Some are also discussed in more detail in the pages on stellar evolution.

Supernovae

A supernova is a cataclysmic stage towards the end of a star's life that is characterised by a sudden and dramatic rise in brightness. A typical supernova may see a star become brighter by up to 20 magnitudes to an absolute magnitude of about -15. This means that a typical supernova may outshine the rest its galaxy for several days or a few weeks.

Supernovae are caused by one of two main mechanisms. The first takes place when accreting material falling onto a white dwarf in a binary system takes it over the mass set by the Chandrasekhar limit. The resulting instability triggers a runaway *thermonuclear explosion* that destroys the star and releases large amounts of radioactive and heavy elements into space. The second process occurs in very massive stars once all the material in their core has been fused into iron. As fusion cannot occur in elements heavier than iron the drop in outwards radiation pressure means that gravitational collapse overwhelms the core which rapidly implodes. The core material gets crushed to form degenerate neutron-density material whilst the extreme temperature and pressure in the surrounding layers cause rapid (R-process) nuclear reactions that synthesise the heaviest elements. A huge flux of neutrinos is thought to interact with the superdense material, ripping the star apart. Such *core collapse* supernovae may result in neutron stars and black holes forming from the remaining core material. More details are given in the later section on star death.

Observationally, supernovae are classified according to their spectra. Type I supernova exhibit no hydrogen lines in spectra taken soon after the supernova event. Those with silicon lines present are further classified as Type Ia and are thought to be due to thermonuclear explosions as in accreting white dwarfs. If no Si lines are present they are Type Ib or Ic depending on the high or low abundance of He lines respectively. These types occur due to core collapse following the outer layers being stripped away in Wolf-Rayet or binary stars.



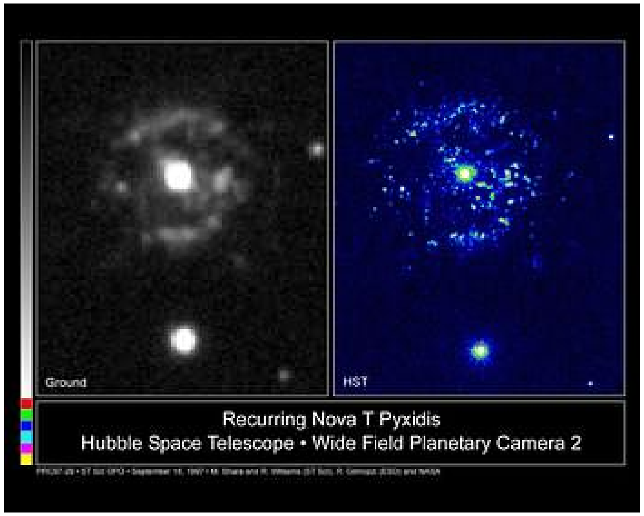
Credit: *Anglo-Australian Observatory*

Supernova 1987A in the Large Magellanic Cloud. The Type II supernova is visible in the left-hand image. The progenitor star is shown in an earlier image on the right.

Type II supernovae show hydrogen lines in their early spectra. They are all examples of core collapse events with most arising due to a massive progenitor star exhausting its core fuel. Perhaps the best known example of this was Supernova 1987A. This was the first supernova visible to the naked-eye since Kepler's supernovae of 1604. It took place in the Large Magellanic Cloud, a satellite galaxy of our own about 50,000 pc distant. Although we expect two or three stars to go supernova in our galaxy each century, these may not be visible in optical wavebands due to absorption and scattering by the galaxy's dust lanes so the occurrence of a supernova in an nearby galaxy was a major boon for astronomers. Observations of SN 1987A continue today at many wavebands.

Novae

A nova occurs in a close binary system and is characterised by a rapid and unpredictable rise in brightness of 7 - 16 magnitudes within a few days. The eruptive event is followed by a steady decline back to the pre-nova magnitude over a few months. This suggests that the event causing the nova does not destroy the original star. Our model for novae is that of an accreting white dwarf. It draws material off its close binary companion for about 10,000 to 100,000 years until there is sufficient material to trigger a thermonuclear explosion that then blasts the shell of material off into space.



Credit: *Mike Shara, Bob Williams, and David Zurek (STScI); Roberto Gilmozzi (ESO); Dina Prialnik (Tel Aviv University); and NASA*

T Pyxidis is a recurrent nova, erupting about every 20 years. HST observations revealed that the eruption is not uniform, rather it produces thousands of gaseous blobs, each about the size of our Solar System. The ring of material in the image is about 1 light year across. The interval between eruptions is much shorter for T Pyxidis than most nova because it is thought its white dwarf is right at the upper mass-limit for a white dwarf. It therefore needs to accrete less material before exploding. For more details read the press release.

Recurrent Novae

These are similar to novae with a change in magnitude of 7 - 16 and a period of outburst of up to about 200 days. They show two or more outburst over recorded observations.

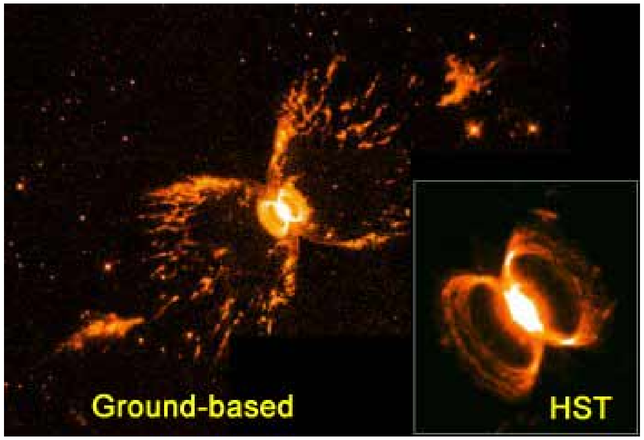
Dwarf Novae

These are intrinsically faint stars that exhibit a sudden increase in brightness by 2 to 5 magnitudes over a few days with intervals of weeks or months between outbursts. Three subtypes are identified; *U Geminorum* , *Z Camelopardalis* and *SU Ursae Majoris* stars. Note as with other types of variables, the class or type name is normally based on the first such type of that class discovered. The *U Geminorum* type is thus named after the star U Geminorum.

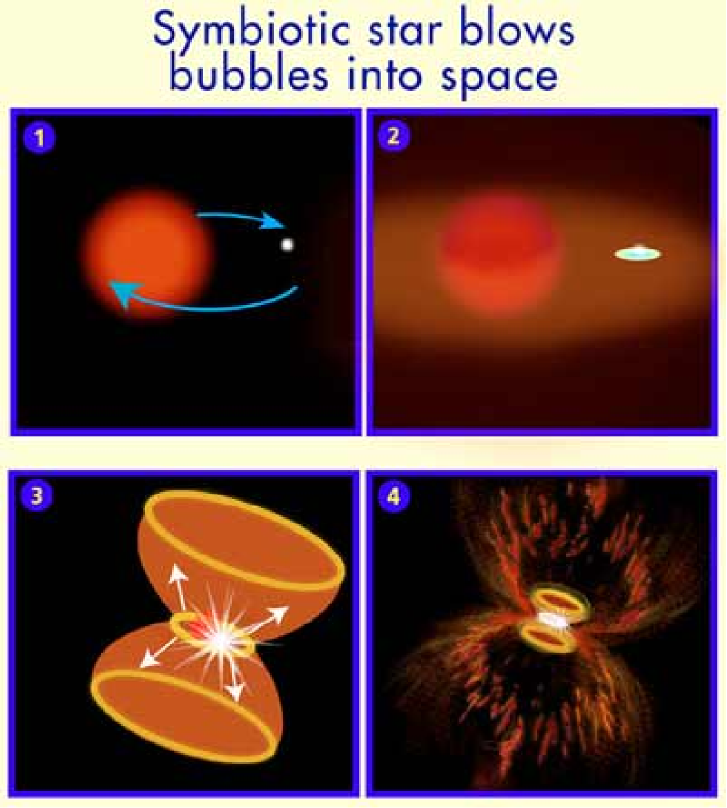
As with other types of novae, dwarf novae are close binaries with a white dwarf as one of the component stars. The most popular model explaining their outbursts is the *disk instability model* in which thermal instabilities in the accretion disk cause outbursts but no explosion. There is no significant ejection of material in these events.

Symbiotic Stars

These systems have a red giant and a white dwarf in a semi-detached binary. Rather than material being accreted by gravitational attraction as with a recurrent novae, in symbiotic systems material is ejected from the surface of the red giant due to stellar wind. The resultant outbursts as material falls onto the white dwarf are less regular and smaller than in other eruptive variables brightening by up to three magnitudes. Examples include R Aquarii and BF Cygni.



Credit: *Romano Corradi, Instituto de Astrofisica de Canarias, Tenerife, Spain; Mario Livio, Space Telescope Science Institute, Baltimore, Md.; Ulisse Munari, Osservatorio Astronomico di Padova-Asiago, Italy; Hugo Schwarz, Nordic Optical Telescope, Canarias, Spain; and NASA*
The large image shows a ground-based image of the Southern Crab Nebula in Centaurus. This nebula is several light years across. The inset shows a HST image of the central region. The hourglass-shaped nebula is the result of a more recent from the symbiotic star system. The following schematic explains how it was produced. For more details read the press release.



Credit: NASA

The following explanation is from the original press release.

1. A pulsating red giant star and a compact, hot white dwarf star orbit each other.
2. The red giant sheds much of its outer layers in a stellar wind. The white dwarf helps concentrate the wind along a thin equatorial plane. The white dwarf accretes some of this escaping gas forming a disk around the itself.
3. When enough gas accumulates on the white dwarf's surface it explodes as a nova outburst. Most of the hot gas forms a pair of expanding bubbles above and below the equatorial disk.
4. A few thousand years after the bubbles expand into space, the white dwarf goes through another nova outburst and makes another pair of bubbles, which form a distinctive hourglass shape.

***R Coronae Borealis* Stars**

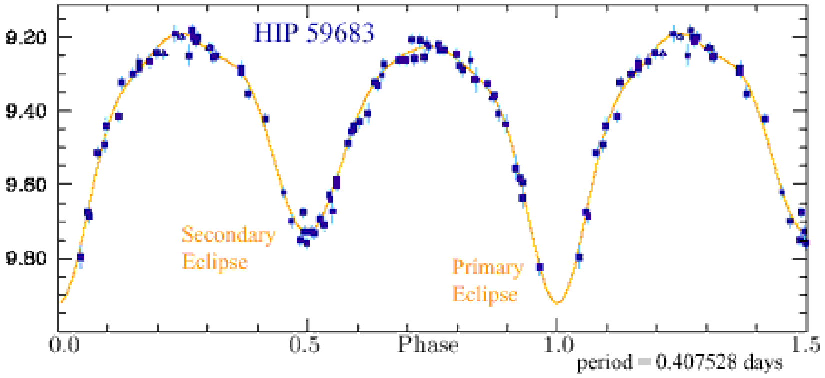
Unlike most variable stars, R Coronae stars spend most of their time at maximum brightness but sometimes decrease in brightness by up to 9 magnitudes at irregular intervals. They they take a few months or a year to return to their normal maximum brightness. These rare stars are carbon-rich.

Extrinsic Variables

Extrinsic variables are those in which the light output varies either due to processes external to the star itself or due to the rotation of the star. The two main classes of extrinsic stars are the eclipsing binaries and rotating variables.

Eclipsing Binaries

The processes behind eclipsing binaries are explained in more detail in the section on binary stars. They are regarded as variable too in that as one of the component stars is eclipsed by the other, the total brightness of the system decreases. The light curves produced by eclipsing binaries show distinctive periodic minima.



Credit: *ESA*

Folded light curve for HIP 59683, an eclipsing binary system. The phase is shown on the horizontal axis with apparent magnitude, *m*, on the vertical axis. Note the two dips in brightness. The deeper drop in brightness is called the *primary* eclipse whilst the smaller drop is the *secondary* eclipse. (Take care with light curves, remember a lower apparent magnitude value, *m*, means a brighter object).

Rotating Variables

Our Sun sometimes has sunspots visible on its surface. These cooler regions appear darker than the surrounding areas. As the Sun rotates the sunspots appear to move across its surface. If we view a side of the Sun with a lot of sunspots it would have a fractionally lower light output than an unblemished side. This principle can be extended to other stars, some of which are thought to have much more active starspot activity. Starspots can be either dimmer or brighter than surrounding regions. As a star with starspots rotates, its brightness changes slightly. Stars exhibiting such behaviour are called *rotating variables*. One type of rotating variables are the *BY Draconis* stars.

Previous: Binary Simulation
Next: Pulsating Variables